Importance of Curing Concrete

By: Anton Schindler, PhD, PE
Professor and HRC Director
Department of Civil Engineering
Auburn University

Presentation Outline

- What is Curing
- Importance of Curing
- Curing Test Specimens
- Closing Comments

What is Curing?

Curing — action taken to maintain moisture and temperature conditions in a freshly placed concrete to allow hydration and (if applicable) pozzolanic reactions to occur so that the potential properties of the mixture may develop (based on ACI CT 2019)

? Effect of Moisture

? Effect of Temperature

Final Curing Methods

Use of wet cotton mats for final curing. Often soaker hoses and plastic sheets are placed over the wet cotton mats to wet cure the concrete.

Final Curing Methods

Application of liquid membrane-forming curing compounds for final curing.

Final Curing Methods

Final curing can be achieved by leaving forms in place. Apply other final curing method after early form removal.
**Presentation Outline**

- What is Curing
- **Importance of Curing**
- Curing Test Specimens
- Summary

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**Importance of Curing**

### Effect of Moisture

1. **Very early-age moisture loss causes increased microcracking**
   - 1) Aggregate Surface
   - 2) Cement Paste
   - 3) Voids
   - 4) Calcium Hydroxide
   - **Microcracks**

(Figure: Bentur and Cohen 1987)

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2. **Moisture is needed for hydration**

(Figure: Emmons, 1993)

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**Plastic Shrinkage Cracking**

- While in the **plastic state** (before setting), shrinkage stresses develop when the rate of surface water evaporation exceeds the rate of bleed water arriving at the surface.
- Surface drying leads to shrinkage stresses when the concrete has very little strength, and hence **plastic shrinkage cracks** develop.

(Source: D&C of Concrete Mixtures, PCA, 2016)

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**Hydration**

- **Water is needed for hydration**

(Figure: D&C of Concrete Mixtures, PCA, 2016)

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**Degree of Hydration**

- **Concrete Age**
- **Concrete State**

**Strength Development**

- **If well cured, then strength**

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**Concrete Age**

- **= Cement Particles**
- **= Hydration Products**
- **Water**

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**Effect of Moisture**

**Moisture**

- **High**
- **Low**

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**Effect of Moisture**

**Lab-cured cylinders**

- **Compressive strength, 1000 psi**

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*Note: The images and diagrams illustrate the concept of hydration and curing in concrete.*
Importance of Curing

**Effect of Moisture**

3. Excessive evaporation before setting can lead to plastic shrinkage cracking
   - Apply curing between placement and final setting to reduce moisture lost from surface
     - a.k.a. initial curing
     - Fogging
     - Evaporation reducers (monomolecular films)
     - After finishing, apply spray-applied, liquid membranes-forming curing compounds

Fogging used as Initial Curing

(Figure: D&C of Concrete Mixtures, PCA, 2016)

Fogging raises the relative humidity of the air over flatwork, thus slowing evaporation from the surface

Role of Water Loss on Drying Shrinkage

**Effect of Moisture**

- Drying shrinkage occurs because of water loss from the hydrated cement paste
- The earlier drying starts, the higher the porosity of the hydrated cement paste, and the greater the drying shrinkage

Effect of Moisture

4. Excessive moisture loss after setting can lead to high drying shrinkage and increased risk of cracking
   - Apply final curing as soon as possible after final setting to reduce moisture loss from surface
     - Wet curing
     - Liquid membranes-forming curing compounds
     - Etc.

Importance of Curing

**Effect of Temperature**

1. Hydration is temperature dependent

   (Source: Samarai et al. 1975)

   (Data from Kjellsen and Detwiler 1992)
Effect of Temperature

2. Rapid hydration at high temperatures may result in loss of long-term strength
   - The slower the hydration products form, the more uniform and dense the microstructure
   - When curing at high temperatures, “shells” of hydration products form around cement grains, which hinder hydration and increase porosity and lowers long-term strength (Verbeck and Helmuth 1968)

Effect of Temperature

What will happen if the concrete is still fresh and it freezes?

4. Provide early-age protection during cold weather
   - Freshly placed concrete must be protected from freezing until sufficient early-age strength (e.g. 500 psi) is reached

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Potential causes of low cylinder strength

- Was the concrete property produced and transported by the concrete producer?
- Was more than the approved amount of water added to the concrete?
- Were the cylinders made, cured, and tested according to AASHTO, ASTM, and/or ALDOT standards?

Can this Cause Low Cylinder Strengths?

- No Tools
- Incorrect Tool
- Poor Strike-off
- Improper Protection During Transport

(Source of images: NRMCA, 2019)

Curing of Cylinders

- Standards for making, curing, protecting, and transporting concrete test specimens:
  1. **AASHTO T23 – Standard Curing**
     - Samples made and cured in the field for acceptance and quality control testing
  2. **AASHTO T23 – Field Curing**
     - Samples made and cured in the field to determine:
       - form or shoring removal time,
       - termination of curing and protection,
       - opening to service, etc.

AASHTO T23 – Standard Curing

1. **Initial Curing**:
   - May last up to 48 hrs
   - Specimens at job site and in molds
   - Shield specimens from direct exposure to sunlight
   - **Store the specimens in an environment that prevents moisture loss**
   - **Temperature**:
     - 60 to 80°F when \( f'c < 6,000 \text{ psi} \)
     - 68 to 78°F when \( f'c \geq 6,000 \text{ psi} \)
   - Record the minimum and maximum temperatures reached during the initial curing period

ALDOT 501: Cylinder Curing Box

1. **Initial Curing: ALDOT 501**
   - The Contractor shall furnish a cylinder heating box equipped with heating and cooling capabilities
   - During initial curing, specimens shall be stored in a **moist** environment between **60 to 80°F**
Why require Curing between 60 to 80°F?

**Effect of Temperature**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Compressive Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 to 50°F</td>
<td>1,000</td>
</tr>
<tr>
<td>50 to 60°F</td>
<td>2,000</td>
</tr>
<tr>
<td>60 to 70°F</td>
<td>3,000</td>
</tr>
<tr>
<td>70 to 80°F</td>
<td>4,000</td>
</tr>
<tr>
<td>80 to 90°F</td>
<td>5,000</td>
</tr>
<tr>
<td>90 to 100°F</td>
<td>6,000</td>
</tr>
<tr>
<td>100 to 110°F</td>
<td>7,000</td>
</tr>
</tbody>
</table>

(Wade et al., 2006)

**Concrete A (hours)**

- Control Data
- Cold Data
- Hot Data

Best Practice:
- Power-up and test curing boxes prior to adding cylinders

(ALDOT 501: Cylinder Curing Box)

1. Cylinder curing box must remain at **60 to 80°F**
2. The cylinders must be cured in the box for **24 to 48 hrs**
3. **Power** for the curing box is thus required for 24 to 48 hrs
4. A maximum/minimum thermometer logger must be in the curing box to record temperatures

**Importance of Correctly Curing Concrete**

1. **Initial Curing: ALDOT 501**
   - During initial curing, specimens shall be stored in a **moist** environment between **60 to 80°F**

**AASHTO T23 – Transporting the Cylinders**

2. **Transport cylinders:**
   - Transport cylinders to the lab within **48 hours** after casting
   - Wait more than **8 hrs after final set** before starting to transport to lab
   - Keep transportation time ≤ **4 hrs**
   - Protect cylinders with **cushioning** material to prevent damage
   - Protect cylinders with **insulation** from freezing during cold weather
   - **Prevent moisture** loss during transportation (e.g. use tight fitting plastic caps)

(Coolers without temperature control do not meet ALDOT requirements)

(Plywood box without temperature control do not meet ALDOT requirements)

(Pictures from John Sorrell and Gene Hightower, ACIA, 2019)

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AASHTO T23 – **Standard Curing**

3. **Final Curing:**
- Start final curing after initial cure, and within 30 minutes of removal from molds
- **Temperature:** 73.5°F ± 3.5°F
- Maintain free water on concrete surface at all times (except when capping and just before ≤3 hours testing)
  - Moist-cure rooms (fog room)
  - Lime-saturated water tank

(Picture: DAC of Concrete Mixtures, PCA, 2016)

**Effect of Non-Standard Curing Conditions**

<table>
<thead>
<tr>
<th>Type of 1-Day Initial Curing</th>
<th>Temperature Range</th>
<th>Relative 28-day Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor exposure: Curing box with temperature-controlled water</td>
<td>71 to 76°F</td>
<td>100 % ✓</td>
</tr>
<tr>
<td>Outdoor exposure: Exposed to sunlight and not protected</td>
<td>71 to 107°F</td>
<td>85 % ❌</td>
</tr>
<tr>
<td>Outdoor exposure: Covered with wet burlap and plastic</td>
<td>94 to 140°F</td>
<td>83 % ❌</td>
</tr>
</tbody>
</table>

Note: Specimens molded at 86°F at the jobsite, subjected to the listed initial curing condition for 1 day, transferred to standard moist room at 73°F for curing until testing at 28 days

(Source: Obla et al., Concrete International, August 2018)

**Effect of Non-Standard Curing Conditions**

- Variation from specified initial curing conditions can significantly affect 28-day strength

(Source: Low Concrete Cylinder Strength, CIP 9, NRMCA, 2014)

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**Closing Comments**

Remember curing is an action taken to maintain moisture and temperature conditions in a freshly placed concrete to allow hydration to occur so that the potential properties of the mixture may develop

**Importance of Curing?**

- **Moisture**
  - Prevent early-age moisture loss to reduce microcracking
- **Temperature**
  - Curing temperature impacts the rate of hydration
  - Moisture is needed to promote hydration and strength development
  - Apply initial curing to mitigate plastic shrinkage cracking
  - Apply final curing to reduce moisture loss and drying shrinkage

**It is essential to PROVIDE good curing!**
Closing Comments

Curing Test Specimens:
- Variation in standard curing of test specimens can significantly affect the measured strength
- It is critical to follow all specified curing conditions for test specimens
  - Make sure concrete curing boxes are ready (including power demands) to maintain specified temperature for 48 hours after placement

References

- ACI CT. 2019. ACI Concrete Terminology. American Concrete Institute
- ACI 214R. 2011. Guide to Evaluation of Strength Test Results of Concrete. American Concrete Institute
- NRMCA. 2014. Low Concrete Cylinder Strength, CIP 9, National Ready Mixed Concrete Association, Silver Springs, Maryland
- Samarai, M., S. Popovics, and V.M. Malhotra. 1975. Effect of High Temperatures on the Properties of Fresh Concrete. Transportation Research Record 924

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- NRMCA. 2014. Low Concrete Cylinder Strength, CIP 9, National Ready Mixed Concrete Association, Silver Springs, Maryland
- Samarai, M., S. Popovics, and V.M. Malhotra. 1975. Effect of High Temperatures on the Properties of Fresh Concrete. Transportation Research Record 924

Thank you for listening.
Questions are welcome!

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